

PAPER • OPEN ACCESS

Multi-Agent Analysis of Scenarios for “Arctic Smart City”

To cite this article: S V Kruglikov and G B Zakharova 2020 *J. Phys.: Conf. Ser.* **1680** 012028

View the [article online](#) for updates and enhancements.



The Electrochemical Society
Advancing solid state & electrochemical science & technology
2021 Virtual Education

Fundamentals of Electrochemistry:
Basic Theory and Kinetic Methods
Instructed by: **Dr. James Noël**
Sun, Sept 19 & Mon, Sept 20 at 12h–15h ET

Register early and save!



Multi-Agent Analysis of Scenarios for “Arctic Smart City”

S V Kruglikov^{1,3}, G B Zakharova^{1,2}

¹ Department of Modeling of Controlled Systems, Ural Federal University named after the first President of Russia Boris Yeltsin, Mira str., 19, Yekaterinburg 620002, Russia ² Department of Scientific Research, Ural State University of Architecture and Art, Karla Libknekhta str., 23, Yekaterinburg 620075, Russia

³ Department of Optimal Control, Krasovskii Institute of Mathematics and Mechanics, S. Kovalevskoi str., 16, Yekaterinburg 620002, Russia

E-mail: s.v.kruglikov@urfu.ru, zakharova@usaaa.ru

Abstract. An approach to formalizing problems of municipal management in the Russian Arctic via smart city technologies is considered on the example of city Salekhard. An analysis of modern smart city concepts and prospects for integrating such technologies as BIM, GIS, and CIM is given. A discussion is based on comparison of two options to implement smart city technologies. Those are: 1) the inertial scenario of development adopted in the Strategy of the municipality Salekhard city, and 2) an alternative scenario corresponding to the innovation model of multicomponent sustainable system which includes energy subsystems. A multi-agent formalization of city management presents specific object features, including factors of the Northern nature. The framework of a four-component model of the flow distribution of resources: material, energy, information, financial, is applied.

1. Introduction

Currently digitalization of urban environment has become a noticeable phenomenon. Smart city technologies in Russia have been actively developed due to state level support. The Ministry of Construction of the Russian Federation has proposed the own project "Smart City" included in the national project "Housing and Urban Environment" being a part of the national program "Digital Economy of the Russian Federation" [1].

In March 2019, the RF Ministry of Construction has adopted the "Smart City Standard" [2] as the basis to form regional standards, fitting to specifics of territories. From the economic point of view the Arctic zone of the Russian Federation (AZRF), an independent state governance object since 2014, is of particular importance. Structured into eight support macro-regions, the AZRF unites the enormous potential of underdeveloped territories, is a strategic resource base and a promising object of socio-economic development. The AZRF includes completely or partially the territories of 9 out of 85 RF constituent entities with 2.3 million inhabitation in 271 municipalities. Severe climatic conditions, such as permafrost, polar night, persistent frosts, require special priorities and a different approach to technological innovation in comparison with adopted in [2].

Modern IT-complexes may drastically change the dwelling and social standards in northern cities and settlements due to the intellectual innovations in order to ensure a decent quality of life, consistent with the goals of sustainable development presented by the UN [3]. Social standards include the confidence of citizens in securing their interests by municipal and regional government. To ensure the trust of citizens to the authorities is among main vital priorities. Regular application of modern IT may



balance a consistent improvement of the socio and technosphere. At the same time, the energy supply subsystem of northern city has to be of priority alongside with, adopted in other territories, the smart city components such as education, health care, security, transport, housing and communal services, ecology, e-government. Smart energy is becoming the leading component of urban housing and communal services that implements intelligent transmission and distribution of electrical and thermal energy, IT energy resource regulation systems. Purposes of such process are to ensure an uninterrupted supply of high-quality energy resources to consumers, to prevent possible emergencies or to minimize their consequences, to ensure safety of the energy management system, to allow transparent observation by consumers of energy resources consumption and payment.

Energy impacts on a fragile environment and the Northern nature is the main source of risks to disrupt the stability of urban infrastructure. Sustainable development is possible only on the basis of advanced planning and high-quality a priori modeling of municipal projects. That determines the demand for smart technologies in Russian Arctic cities.

The first section of the paper, based on native and foreign reference, presents a survey of the development, relationships, hierarchy, and interpretations for such concepts as smart city, building information model (BIM), geographic information system (GIS), city information model (CIM), and city digital twin; as they formed in foreign and Russian segments. Other sections interpret and fill with content these concepts in the frame of proposed conceptual scheme and the corresponding model of the centrally controlled information platform "smart northern city".

Further, to analyze is selected Salekhard, the administrative center of the Yamal-Nenets Autonomous Okrug (YNAO). The proposed conceptual scheme corresponds with provisions of the "Strategy for the social and economic development of Salekhard until 2030 [4] (hereinafter referred to as the Strategy). The document states that the dominant (up to 80% of volume) industry of the city – the production and distribution of heat, electricity, gas, and water. Thus, the city's industry ensures the survival in the harsh climatic conditions but it cannot provide the competitiveness on the market. The federal level tasks, solving by the city, are to ensure the coherence and infrastructural support of the governmental power in the YNAO region. This justifies the inclusion of Salekhard in the integration projects for rise the energy and transport connectivity of the RF territory.

The paper examines a smart northern city as a controlled system in terms similar to a four-component macroeconomic model, and restricts by city management analysis within processes of hierarchical flow distribution for resources of four types (material, energy, information, financial). That allows to apply systematically a multi-agent approach to modeling the interaction of hybrid systems based on the theory of a priori guaranteed control and estimation under uncertainty.

The novelty of the approach is that contrary to a routine inertial scenario to manage the implementation of the "smart city" project, the possibilities of centralized governance for innovating of multicomponent hybrid subsystems of the northern city, including energy ones, are considered.

2. Evolution of the concept Smart City

Nowadays there is no unified definition for Smart City, but there is some basic understanding allowing to develop rapidly in a range of countries the corresponding IT-complex, determining the level of city intellect. The systematic vision of a smart city was been changing while the concept evolution, transforming from originally technocratic to a more humanitarian one. The last supposes active involvement of residents in city management processes applying digital platforms, and also to solve many life support issues via appropriate (most often cloud) services. Various researchers offer their own versions of Smart City concept. The research report by McKinsey provides a diagram of smart city concept transformations [5, p. 7], starting in 2008, when IBM announced the Smart Planet program. The first period, Smart City 1.0, has finished in 2013 with some decline in development, but already in 2016 a new stage has been announced, Smart City 2.0, with the focus on residents interests.

The analysis of global practice presented in report of the Center for Strategic Research "North-west" allows to identify three sequential stages of the smart cities formation [6, pp. 5-6] which reflect changes in key technologies and types of projects being implemented. Smart City 1.0 is focused on

technologies, physical infrastructure is being re-equipped, and individual IT solutions are being implemented. Key stakeholders provide solutions and services. Smart City 2.0 is a high-tech driven city. Technologies are being used to improve the quality of life and solve problems in the fields of health, transportation, the environment and ecology. The 4G mobile radio standard, IoT, high-speed and mobile Internet access are being introduced. The city authorities have the main role in the city development. Smart City 3.0 is a highly intelligent integrated city that allows real-time collection and analytics of data, implementation of process management in all areas of infrastructure. This unified system contributes to the involvement of citizens in the development of the city. Thus, in modern understanding, the concept of Smart City is not limited to technology as the main factor of development. Really smart cities ought to have all the conditions for the human capital growth.

The need to implement in a smart city green living standards, corresponding to sustainable development, is an important aspect. The 17 requirements formulated by the UN Sustainable Development Goals (SDG) [3] provide a detailed idea of the system of priorities to meet the economic, social, environmental and cultural needs of the present and future generations. From the point of view of this study, the following goals are of interest:

SDG 3: Ensure healthy lives and promote well-being for all at all ages.

SDG 7: Ensure access to affordable, reliable, sustainable and modern energy for all.

SDG 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.

SDG 11: Make cities and human settlements inclusive, safe, resilient and sustainable.

Recently smart city technologies in Russia are actively developing. Up-to-date information contains the Internet portal "Smart City" [7] presenting legal regulations, informative materials. It includes the "Smart City Solution Bank", with ready-made solutions in such areas as energy efficiency; security; wastes management; water, energy, and heat providing; transport; construction; ecology; information city.

To assess the efficiency of the current changes, the RF Ministry of Construction has developed the unique technology for evaluating an urban environment quality index involving 36 indicators [8]. The interactive map there displays indexes for 1114 cities. Salekhard with the score 210:360 has a favorable urban environment. In December 2019, the project was approved on IQ indicators of cities participating in the implementation of the Smart City project in 10 areas of digital transformation of urban economy [9].

Returning to Smart City 3.0 we can position this level as the digital twin (DT) of the city. At the World Economic Forum Davos-2019 "CityZenith" company has presented an interactive 3D real-time simulation of Amaravati, the Indian city, where hundreds of IoT systems and publicly available databases are combined into a single portal [10]. Similar DT projects have been developed for Singapore, Glasgow, Boston and other cities. Real-time data offers more tools and information than static data models. The simulation capability allows you to play out virtual development scenarios, investigate the influence of various factors, track construction progress, environmental conditions, energy consumption, public safety, etc.

In the Russian segment a special approach has been adopted to the DT concept which is noted in the "Smart City Standard" and sets the initial positions and the vector of development. The subsection "City management" in the "Standard" [4] presents DT which will be constructed to solve resource management problems on the basis of information systems for urban planning activities, supported by geographic information systems (GIS). There are some samples [11]: a municipal system is developing in Ufa, including hundreds of specialized layers. For each territory fragment there is information on engineering infrastructure, transport, housing stock, etc. By the matter of fact, this DT definition corresponds to the current digitalization level of Russian cities and ultimately leads to Smart City 3.0.

A huge experience has now been accumulated recently in the field of building information modeling (BIM). For example, the overview analysis [12] covers hundreds of BIM reference. An information model as an intelligent source of interrelated data on object all over the entire life cycle may be integrated into the GIS platform. Then one may talk about the concept of city information modeling

(CIM). This model involves information on natural landscape, buildings and infrastructure. One may integrate BIM technology and GIS as in [13], for example, where a data schema based on IFC and CityGML formats is considered. Nevertheless, there are few BIM projects to deal with constructing on permafrost either dwelling buildings or infrastructural facilities.

Summarizing the brief overview of Smart City concepts, one may conclude that varieties in definitions concern only to a choice of reference points and are ultimately aimed at one, ideal, understanding of Smart City being a benchmark to develop relevant technologies.

3. The inertial scenario of development for Northern city Salekhard

A particular problem to implement a smart Northern city energy supply and consumption technologies is discussed. The Russian Arctic territory is divided on eight basic longitudinal regions (support zones) in accordance with the types of natural resources flow generated there. The fourth support zone specializing in gas and oil recovery includes Yamal Peninsular, where the most promising for the next semi century the liquefied natural gas producing cluster with possible annual capacity up to 70 ml tons is located. Significant incomes of regional budget allow to invest in transport networks over permafrost and to subsidize municipal costs on energy supply and central heating. Annually problems of efficient budgeting is sharpening, in particular, for the municipal community Salekhard, the capital of YNAO. It is the compactly located on the Polar circle, developing settlement with rather advanced infrastructure for 52 thousand inhabitation.

Salekhard is chosen here for a systematic analysis in accordance with the multi-agent version of system approach [14]. It allows to describe efficiently for various practical applications including those under uncertainty and risk [15] wide classes of technical objects and abstract notions. Similar terms of agents and multi-agent systems (r/v/i)MAS present either real (r: equipment, mechanisms, vehicles) or virtual (v: agreements, messages, images, plans, programs, software) or intelligent (i: personal, organizational systems). For example, an informational system or an IT-platform may be presented by (r)MAS including on the lower level <hardware~(r)MAS, software~(v)MAS, staff~(i)MAS || Business Processes ~ technologies>. Intelligent agents or MAS are able to form a situation reflection in their internal information space.

In accordance with the multi-agent approach Salekhard being a controlled system (CS)~{G: Environment || M: system of control; B: mechanism; C: object of control} is a (r)MAS. A verbal image of the city gives the Strategy, (v)MAS. Inclusion of a digital twin in a smart city CS structure may transform it into (i)MAS.

The Strategy has presented M: understanding of correspondence of Salekhard development prospects on decade period and C: problems of current status. Features of the city development concept are as follows.

- **G:** By the matter of fact, environment, the harsh circumpolar climate with a heating period (GSOP) of more than 7000 degree days is supposed to be invariant up to 2030. The important natural factor, permafrost, is only once mentioned on 80 pages of the strategic planning document. Thus, the Strategy does not consider possible climatic conditions changes that create a risk of disrupting the city infrastructure stability.

- **G:** The responsibility delineation for participants in the Salekhard development process is reflected. However, the government of YNAO is actually considered as a component of the external environment, whose actions are not amenable to correction. To a certain extent, this may be justified by the independence of the municipal level in governmental hierarchy fixed in the RF Constitution. This item is corrected by an amendment adopted popular vote on July 01, 2020.

- **B:** In the current state of the municipality the problems relevance of the Smart City 1.0 level is shown. That are: the state of the housing stock; material flows processing (water intake, sewerage and wastewater treatment, garbage collection and processing); compliance with life support standards for the population, in particular, the national settlement Pelvovzh, etc.

- **B:** The dominant branch of the city's business, the production and distribution of energy resources and water, determines on more than 80% of industrial production. Municipal JSC "Salekhardenergo" is

a leading nearly monopoly supplier of material resources and energy flows for the population. Therefore, technologically motivated controlled changes in volumes and costs of services may decrease the gross domestic product of city.

• **B**: The task has been set to implement "smart city" technological solutions by decentralized efforts of groups of IT enthusiasts, a way to involve socially active citizens in city problems solving same as [16].

The Strategy analysis shows that the inertial scenario of the consistent city development is accepted as the main. The target criteria (indicators) given in section [4, p.74, Task 2.2] demonstrate the limitations of this scenario, in particular, anticipating the degradation of the city's housing stock.

Therefore, it makes sense to examine alternatives for intensive development. One is a centrally governed project of Smart City 2.0 level implementing to create a digital twin. This case allows to realize in Salekhard a multicomponent hybrid energy system combining the innovated energy supply subsystem and a newly creating subsystem to control the state of the engineering infrastructure in permafrost. The economic viability of the project depends on possible savings of energy resources and reducing losses from the destruction of engineering infrastructure. Preliminary expertise and data on Yekaterinburg [17] show possibility to cut up to 15% of resource consumption.

4. Multi-agent approach to smart northern city problem statement

Let $[i|j|k(:)n]QX0 \sim \{y||f/y^*||f^*\}$ be (v)MAS corresponding to the Arctic municipal community Salekhard, (r)MAS. $QX0$ includes $y^*||f^*$ reflecting the city in financial and documentary SMART images. In accordance with the Strategy $[i|j|k(:)n]QX0$ involves four main interacting components (r)MAS $[i|j|k-1(:)n \in N = \{0, \dots, 4\}]QX0 \sim \{G0||M0,B0,C0\}$ Fig.1. There **G0**: external circumstances, involving environmental, governmental and societal influence of participants higher then municipal levels; $k^* > k$. **M0** denotes Salekhard municipal authorities; **B0** is local business of enterprises and companies, including the "Salekhardenergo" company **b0** as well as trading, transport and financial intermediaries; $b_j \in B0$. **C0**: population and societal subsystems.

Strings as $X(-2-)Y$ denote interactions that may be on different levels; where **X** and **Y** $\in \{G0||M0,B0,C0\}$. The strings **M0**(-2-)**C0** and **C0**(-2-)**C0** present interconnections of socio sphere; **B0**(-2-)**B0** and **B0**(-2-)**C0** are mainly for economics and techno sphere including energy generation, transport, and supply processes. To regulate the energy flows is responsibility of **b0** $\in B0$. It is near to be monopoly in $(m||e)$ supplies for Salekhard dwellers. Moreover, as a municipal entity **b0** is the main real asset and the municipal budget payer.

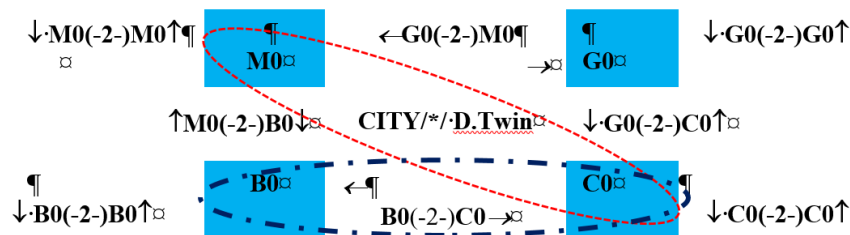


Figure 1. (r)MAS presenting the city in accordance with the Strategy [4].

That means the necessity to balance double circuits of $(m||e)g$ material and energy flows and of $(i||f)g^*$ information and finance dual ones, presented in Table1. Here $(m||e)g/(f||i)g^*$ circuits' equilibrium is considered in accordance with the duality principle scheme of mathematical guaranteed control-observation problems under uncertainty [18]. Correspondent equality in linear approximation cases is the following:

$$\text{Min}_U \text{Sup}_X \{F(U) \eta \mid \eta \in W\} = \text{Min}_U \text{Sup}_{X\#} \{F^*(U\#) \zeta^*\} \quad (1)$$

Table 1. Double circuits of dual flows (m||e)g and (i||f)g*.

	$[iJ k(:)n]g/g^*$	$[iJ: (m e) k-I(:)n]g$	$//[iJ^*: (f i) k-I(:)n]g^*$
(1)	$(e)g (m)g$	$(m) \mathbf{G0(-2-)} \mathbf{B0(-2-)}\mathbf{C0} \mathbf{M0}$	$(e) \mathbf{M0} \mathbf{B0(-2-)}\mathbf{C0(-2-)}\mathbf{G0}$
(2)	$//(f)g^* (i)g^*$	$//(f) \mathbf{B0(-2-)}\mathbf{C0(-2-)} \mathbf{M0} \mathbf{G0}$	$(i) \mathbf{M0 (-2-)} \mathbf{B0(-2-)}\mathbf{C0} \mathbf{G0}$

(1) Energy flows $(e)g$ correspond to the following chain of interactions. Weather $\mathbf{G0(-2-)} \mathbf{G0}$ forms challenges $\mathbf{G0(-2-)}\mathbf{C0}$ to the city inhabitation which ought to be met by adequate energy flows $\mathbf{B0(-2-)} \mathbf{C0}$ generated by interaction $\mathbf{B0(-2-)}\mathbf{B0}$. To satisfy expectations of inhabitants $\mathbf{C0(-2-)}\mathbf{C0}$ and standards adopted by municipal authorities $\mathbf{M0(-2-)}\mathbf{C0}$ is an aim of prognostic planning of $\mathbf{M0(-2-)}\mathbf{M0}$. Closed loop flows $(m)g$ of heating system have sequenced in possible threats and risks for infrastructure especially in permafrost by the large volumes of central heating $\mathbf{B0(-2-)}\mathbf{G0}$.

(2) $(f||i)g^*$ circuit reflects interaction in financial and information images which may be a part of digital twin. $\mathbf{B0(-2-)}\mathbf{B0}$ are $b0 \in \mathbf{B0}$ costs for purchasing primary energy resource from market suppliers. Dwellers ought to compensate $\mathbf{C0(-2-)}\mathbf{B0}$ these costs in accordance with tariff regulation $\mathbf{G0(-2-)}\mathbf{B0}$ of regional authorities. Inhabitants payments are partly subsidized by the budget cash flow: $\mathbf{G0(-2-)}\mathbf{M0 (+)} \mathbf{M0(-2-)}\mathbf{B0}$.

Problem (MA2). Risk management on operational level under hybrid energy supply by centralized and distributed facilities is necessary because of possible stability threats of $(f||i)g^*$ flows for main participants as results of local modernizing solutions. Herein the interactions include $\mathbf{G0(-2-)}\mathbf{M0}$ subsidies of regional budget, $\mathbf{B0(-2-)}\mathbf{C0}$ payments of $b0$ based on $\mathbf{C0(-2-)}\mathbf{B0}$ cash flow in a chain of intermediaries. Systematic risk analysis is necessary. However, the high uncertainty of certain projects requires to involve significantly different from usual "IF...THEN..." procedures. Quantitative risk management techniques based on the practice of financial assets investing include such as a VaR-criterion and a real options procedure. The best possible decision has to include variable behavior with respect to further situation development. The practical implementation of a pre-made decision may be delayed until situation is clear.

Problem (MA1). A technological modernization of dwelling facilities and resource suppliers, avoiding environmental damages and erosion permafrost, forms the tactical planning level. The problem is to determine the most efficient organizational chart and duration of the modernization cycle. It is known that energy infrastructure changes are lagging behind the logistics and IT-infrastructure ones. The necessary functions set $F\#$ of (r)MAS under modernization ought to include: (1) minimizing the loads on permafrost; (2) stable cash flow to the municipal budget; (3) respectively stable payments of inhabitants; (4) to preserve the subsidies level from $\mathbf{G0}$. Possible alternative solutions may be connected with incorporating in city practice $(m||e)$ active cooling techniques.

Problem (MA0). To choose the optimal (r)MAS as a $(m||e)//(i||f)$ production chain providing $F\#$ set of functions under various city development dynamics. An efficient solution has to integrate the synergy of organizational, energy, information, communication technologies; including those of DT.

Alternative ways to solve the Problem (MA0) are considered. (1) To provide $b0 \in \mathbf{B0}$ with additional operational functional $f \in F\#$. (2) To establish new specialized municipal company, special Agent $[iJ||kI(:)nI] yI||fI \sim b\# \in \mathbf{B0}$ an intermediary providing on the local market a seasonal permafrost regulation in competing or cooperating with $b0$. (3) To engage free market engineering company in the niche. Chances are but rather low because of high risks, strict market regulations and low demand.

Investment sources may be a regional loan and/or a venture capital of RF level ensured by economy of current inhabitation cash flow. The economic efficiency analysis in standard discounted indicators of the investment process (NPV, IRR) have to consider separately.

5. Conclusions

The paper presents the results of research alternative ways to intensive development of the Northern city Salekhard. A centrally governed project of the Smart City 2.0 level implementing creating a digital twin is discussed. This case allows to realize in Salekhard a multicomponent hybrid energy system combining

the innovated energy supply subsystem and the newly created subsystem to control the state of the engineering infrastructure in permafrost. Wherein a multi-agent formalization for city management is proposed for the model of multicomponent sustainable system. The economic viability of the project depends on possible savings of energy resources and reducing losses from the destruction of engineering infrastructure.

Acknowledgments

The reported research was partly funded by Russian Foundation for Basic Research and the government of the Yamal region of the Russian Federation, grant № 19-48-890001.

References

- [1] Passport of the national program "Digital Economy of the Russian Federation" 2019 *Russian Government* Retrieved from: <http://government.ru/info/35568/>
- [2] *Basic and additional requirements for smart cities (Smart City Standard) Approved by the Deputy Minister of Construction and Housing and Utilities of the Russian Federation 04.03.2019* Retrieved from: <https://www.minstroyrf.ru/docs/18039/>
- [3] 17 Goals to Transform Our World *Web site of the United Nations "Sustainable Development Goals"* Retrieved from: URL: <https://www.un.org/sustainabledevelopment/ru/sustainable-development-goals/>
- [4] The strategy of socio-economic development of the municipality Salekhard until 2030 Decision of the City Duma of Salekhard of December 21, 2018 N 91 Retrieved from: <http://docs.cntd.ru/document/550285222>
- [5] Smart city technologies: what influences the choice of citizens? July, 2018 *McKinsey center for government*. Retrieved from: https://www.mckinsey.com/ru/~/_media/McKinsey/Industries/Public%20Sector/Our%20Insights/Smart%20city%20solutions%20What%20drives%20citizen%20adoption%20around%20the%20globe/Smart-city-solutions-What-drives-citizen-adoption-around-the-globe-RU.ashx
- [6] Technologies for smart cities *Report of the Center for Strategic Research "North-west"* Retrieved from: http://www.csr-nw.ru/files/publications/doklad_tehnologii_dlya_umnyh_gorodov.pdf
- [7] *Smart City Solutions Bank* 2019 Retrieved from: <https://russiasmartcity.ru/projects>
- [8] *Urban environment quality index* 2019 Retrieved from: <https://индекс-городов.рф>
- [9] Order of the Ministry of Construction of Russia on the approval of the methodology of the digitalization index of urban economy IQ cities. *Portal of the project "Smart City"* Retrieved from: <https://russiasmartcity.ru/documents>
- [10] Minsky C 2020 January 29 Digital twins give urban planners virtual edge *Financial Times* Retrieved from: <https://www.ft.com/content/15851b06-1b6f-11ea-81f0-0c253907d3e0?shareType=nongift>
- [11] Mustafin U M 2019 *Towards a digital twin of the city* (Moscow: Bulletin of the Moscow Government University Press) No 4 (46)
- [12] Gao X and Pishdad-Bozorgi P 2019 BIM-enabled facilities operation and maintenance: A review *Advanced Engineering Informatics* No 39 pp 227-247 (ResearchGate: the professional network for scientists and researchers) (*Electronic Materials*) DOI: 10.1016/j.aei.2019.01.005
- [13] Xu X, Ding L, Luo H and Ma L 2014 From building information modeling to city information modeling *Journal of Information Technology in Construction (ITcon), Special Issue BIM Cloud-Based Technology in the AEC Sector: Present Status and Future Trends* vol 19 pp 292-307 Retrieved from: URL: <http://www.itcon.org/2014/17>
- [14] Gorodetsky V I 2012 Self-organization and multi-agent systems. I. Models of multi-agent self-organization *Izvestiya RAN. Theory and control systems* No 2 pp 92-120 (in Russian)
- [15] Kruglikov S V 2014 An A Priori Planning of Joint Motions for USV as a Problem of Guaranteed

- Control *Applied Mechanics and Materials* vol 494-495 pp 1110-13
- [16] *Science and Technology Policy Institute. Living Lab Methodology* Retrieved from: https://u4iot.eu/pdf/U4IoT_LivingLabMethodology_Handbook.pdf
- [17] *Open housing* Retrieved from: <http://xn--elackcqbno8a1d.xn--plai/ords/f?p=121:9>
- [18] Kruglikov S V 2017 A problem of optimal control and observation for distributed homogeneous multi-agent system *AIP Conference Proceedings* 1910, 060007 (*Electronic Materials*) <https://doi.org/10.1063/1.5014001>